# AN INVENTORY OF SURFACE WATER RESOURCES
# IN
# GRAND CANYON NATIONAL PARK, ARIZONA

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A Final Report to the
Division of Resource Management
Grand Canyon National Park
Part I (Water Resources Inventory) of
the 208 Water Quality Project

ABSTRACT

Data were gathered in the Grand Canyon region of northern Arizona on the location, history, quality, and permanence of surface water resources in a 1,881-square mile study area. The availability of water was found to be closely related to geologic structure, seasonality, annual precipitation, and other factors. Fifty-seven perennial water sources have been identified on the basis of historic records and vegetative analysis, comprised of 21 perennial streams and 36 perennial seeps or springs which may or may not feed into the perennial streams. The Muav Limestone is the major geologic formation in which perennial seeps and springs arise, although other formations may be of local importance.

Intermittent and ephemeral water sources predominate in the region, with the major perennial streams (with the exception of the Colorado River) being related to large perennial spring systems on both the north and south sides of the Colorado River. Natural lakes have been formed as a result of surface subsidence in some areas with a substrate consisting largely of Kaibab Limestone. Playa lakes are absent from the primary study area, and are rare in the region. Artificial surface water sources include wells, improved springs, and catchment tanks. A preliminary classification scheme for surface water sources in the Southwest was developed.

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CONTENTS


| | |
|---|---|
| Abstract | ii |
| Acknowledgements | iii |
| Contents | iv |
| Introduction | 1 |
| Methodology | 3 |
| Results | 6 |
| Discussion | 11 |
| Summary and Conclusions | 12 |
| Appendix A: History of Hydrogeographic Research, Grand Canyon National Park | 12 |
| Appendix B: Geology and Water-Bearing Properties of the Formations | 21 |
| Appendix C: Bibliography-Water Resource Inventory, and U.S. Geological Survey Bibliography | 27 |
| Appendix D: Research Design | 46 |
| Appendix E: Computer Classification | 55 |
| Appendix F: Water Quality Testing-Interpretation of Results | 58 |
| Appendix G: Mean Precipitation and Temperature, Grand Canyon National Park | 59 |
| Appendix H: Vegetation as an Indication of a Perennial Water Source | 60 |

Introduction:

The availability and seasonality of water in a primarily arid region such as Grand Canyon National Park dictate the fact that water is a precious commodity, much in demand by man and the biota. The surface water resources of Grand Canyon are characterized by a situation in which intermittent streams predominate, a ground water table as such does not exist, rainfall is seasonal and highly variable, scattered perennial water sources are related to large spring systems which arise from predictable geologic formations, and other features. This situation is clearly at contrast to the permanent presence of the Colorado River at the bottom of the canyon, or to the 300-plus inches of snow which may be recorded on the North Rim in a record winter. However, the key to water at Grand Canyon is its availability: the Colorado River is there but so inaccessible to everything with the exception of its most closely associated ecosystems of aquatic and riparian life that it is, for the most part, unavailable to the surrounding arid environment. Likewise, the North Rim snow must quickly melt, runoff, evaporate, and percolate into the extremely porous substrate.

An inventory of surface water resources in an arid region is an integral component of any comprehensive resource basic inventory (ecological survey) of the region. This water resource inventory, although not a direct part of the current ecological survey of Grand Canyon, will serve to complement information generated by the ecological survey. Final application of the inventory may result in a solution of identified resource management goals, or as a reference for research. With these and other applications recognized, the objective of this study is two-fold: to inventory the surface water resources of Grand Canyon National Park (within the study area) and immediately adjacent areas with respect to their access by, and public health of, humans, i.e. hikers and back-country users, and secondly, to inventory these water resources in regard to their support of natural ecosystems, i.e. primarily wildlife and riparian ecosystems.

Previous water resources research in the Grand Canyon region, while providing a wealth of information on various topics pertaining to the availability and location of local water sources, has not produced an organized system of information on regional hydrology with a combined emphasis on inventory, hydrologic data access, backcountry user needs, and wildlife and environmental concerns. Many spring sites and water locations are noted in a variety of historic and recent literature sources. However, perennial water sources, so important to wildlife and man, have only been partially identified. As the majority of the region is extremely arid, much work has been done to define the geologic occurrence of ground water supplies, mostly by the U.S. Geologic Survey (USGS), in order to locate potentially productive drilling sites. A great deal of the previous water research done within the study area encompassed by this report has been oriented toward indentification of perennial water

sources to meet the present demand for water for domestic consumption in Grand Canyon Village. The USGS maintains extensive files with regional spring and well data, but much of this information is presently unpublished or, similar to USGS stream-gaging station records from the region, is available in a variety of miscellaneous publications and has not been organized into a composite reference for the area. The results of this report are organized in such a way as to combine all historic literature, research, and regional surface water resource information.

No scientific information on Grand Canyon or local water resources was available until publication of "Report upon the Colorado River of the West" (Ives 1861), which contained some mention of local water sources and availability. In 1869, Major John Wesley Powell explored the length of the Green and Colorado Rivers by boat, and in his journal, "Exploration of the Colorado River of the West" (Powell 1875), notes the presence of water sources. Shortly thereafter, Dutton's "Tertiary History of the Grand Canyon District" (Dutton 1882) was published by the USGS, outlining regional spring locations and other exact water resource information. Publication of the Bright Angel, Shinumo, and Vishnu Temple topographic maps by USGS, between 1906 and 1908, illustrate tanks, spring sites, and known perennial streams, and in conjunction with USGS publication of "The Shinumo Quadrangle, Grand Canyon District, Arizona" (Noble 1914) presented a complete picture of water resources for the region as known at the time. In 1923, the USGS began operating a permanent stream-gaging station on Bright Angel Creek, and also began operating a gaging-station on the main Colorado River above its confluence with Bright Angel Creek in 1925. "Water Power and Flood Control of the Colorado River Below Green River, Utah" (LaRue 1925) was published by the USGS, presenting data on available water sources and tributary flow into the Colorado River throughout the region.

With the creation of Grand Canyon National Park in 1919, rangers and naturalists began recording information regarding regional surface water resources. Park Naturalist Edwin D. McKee wrote "The Coconino Sandstone--It's History and Origin" (McKee 1933) and many other papers concerning Grand Canyon geology with additional notes on water sources. Beginning in the 1930's and continuing, at intervals, into the 1970's, North Rim Unit rangers recorded spring discharge and locations, providing much historical information on spring sites inventoried for this project.

Domestic water for the rapidly expanding Grand Canyon Village on the South Rim originally came from local springs such as Rowe's Well or earthen catchment tanks, was later brought in by railroad tank-cars, and beginning in the 1920's was pumped up from one of the several large springs at Indian Gardens. However, in the 1950's this supply was seen as inadequate to meet the park's projected demand. The National Park Service began monitoring local springs at this time for possible sources of domestic water for Grand Canyon Village. As a result, detailed flow records exist for springs such as Haunted Spring, Phantom Spring, and

others, data that was gathered before Roaring Springs was chosen to supply domestic water to the South Rim in 1970. In conjunction with this search to locate a larger domestic water supply for the South Rim, the USGS initiated research which resulted in the publication of "Geology in Relation to Availability of Water Along the South Rim, Grand Canyon National Park, Arizona" (Metzger 1961). This publication identifies all known water sources along the main South Rim with detailed flow descriptions and geologic locations, discussing the relationship between geology and local spring sites.

The USGS has gathered the majority of recent water resources information for Grand Canyon. In a search for water, similar but not related to the search for a South Rim domestic water supply, the USGS published "Geology and Promising Areas for Ground-Water Development in the Hualapai Indian Reservation, Arizona" (Twenter 1962), likewise noting the relationship between geology and local spring locations to identify possible drilling sites to provide water for livestock. "Spring Flow into the Colorado River: Lees Ferry to Lake Mead, Arizona" (Johnson and Sanderson 1968), published by the USGS, describes briefly many known springs and has compiled all additional discharge data on the sites. With the updating of regional topographical maps in recent years, files are kept regarding all spring and well sites identified by the USGS. These files are only partially published as a series of maps showing local ground-water conditions (Farrar 1979), with detailed data regarding spring and well locations, elevation, geologic formation, discharge, specific conductance, and fluoride concentrations. The most recent research into regional hydrology has been by Peter W. Huntoon, whose works include research on karst hydrology (Huntoon 1968, Huntoon 1974), hydro-mechanics of local ground-water systems (Huntoon 1970), and "The Relationship of Tectonic Structure to Aquifer Mechanics in the Western Grand Canyon District, Arizona" (Huntoon 1977). For a more detailed account of the history or publications of Grand Canyon water resources information, see Appendix A, History of Hydrogeographic Research, or Appendix C, Bibliography--Water Resource Inventory.

METHODOLOGY:

For the primary Water Resource Inventory, Fiscal Year 1979, the study area consisted of the eight main 15-minute USGS quadrangle maps (USGS, Wash., D.C.) in Grand Canyon National Park, Arizona:

| | |
|---|---|
| BRIGHT ANGEL | NANKOWEAP |
| DEMOTTE PARK | POWELL PLATEAU |
| HAVASUPAI POINT | SUPAI |
| KANAB POINT | VISHNU TEMPLE |

The study area is located entirely in Coconino and Mohave counties and includes adjacent areas outside the park boundaries but within range of park wildlife and hikers. The area encompasses 1,881 square miles.

The topography of the Grand Canyon is unique in that it is the deepest and most extensive canyon found in the plateau country. The study area is bounded on the east and west by sharp structural breaks and falls. The availability of surface-water relates directly to this extraordinary geological structure and regional dip. See Appendix B, Geology and Water-Bearing Properties of the Formations, for a more detailed discussion of specific Grand Canyon topography.

Precipitation comes in the form of summer thunder showers and winter snows. Average annual precipitation varies from more than 25 inches along the forested North Rim (9,000 feet) to less than 9 inches on the deserts of the Inner Canyon (2,400 feet). As a general rule, the temperature increases as one descends into the canyon. See Appendix G, Mean Precipitation and Temperature, Grand Canyon National Park, for a more detailed listing of temperature and precipitation.

The first phase of the Water Resource Inventory (see Appendix D, Research Design) was to derive as much information on water resources as possible from maps, literature searches and personal communication. The literature search covered the libraries of Grand Canyon National Park, Northern Arizona University, Museum of Northern Arizona, and USGS, Flagstaff, as well as the office files in the park Resource Management Division, Inner Canyon Division and Division of Maintenance. Personal communications were carried on with scientists doing past or current research in the park (Dr. Stan Brickler, Dr. R. Roy Johnson, Dr. R. C. Euler, Dr. Jon Rodick), the park River Unit and Inner Canyon Unit.

Phase two of the inventory project was to supplement phase one information with field data from areas identified as lacking water resource data. Due to the unusual and limiting nature of the Grand Canyon, field work took on many forms. Only limited work was done by foot due to the time factor involved with access to areas. The North Rim was searched mainly by vehicle, as was the South Rim. The Colorado River within the study area was traversed via the Park Service patrol boat. Helicopters were used extensively to visit hard-to-reach sites (Shinumo Amphitheater, Crystal Creek, Nankoweap Basin, etc.) to sample flow and vegetation. Helicopters, due to their manuverability, were also the best means of locating a stream source. Fixed wing reconnaissance flights were also used to locate sources.

A Water Resource Inventory field card was developed (Appendix D) to ease data collection, organize information in a uniform style and for use by people other than the authors of this report. The card included in Appendix D is the third revision of the initial design after being field tested. The site number which appears on every field card is a combination of the USGS quadrangle name abbreviation (i.e., Supai=S, Vishnu Temple=VT) and a number for the site (i.e. 1, 2, 3, etc.) based on chronological entry. Definitions of terms used are in Appendix D. The term 'seep' and 'spring' are differentiated in that a seep is a wet area or dense

cluster of vegetation that indicates presence of water; most seeps are assumed to discharge less than 5 gal/min (Huntoon 1977).

The cards are permanently stored with the Division of Resource Management, Grand Canyon National Park, in a file box under the quadrangle name for easy access and each site is noted on the corresponding USGS quadrangle map used for this purpose.

All known water sources in the park are classified according to the classification scheme in Appendix D. This final classification scheme was designed for regional needs (as no existing scheme was found appropriate) and adopted for the project. It addresses biological concerns, endangered or threatened species as required by law, political concerns, limnological concerns and public health and access. This numerical classification permits a meaningful grouping of surface sites and easy computer storage and mapping of data.

The initial step in classification of a water site is defining and categorizing the source in accordance with the first three numbers in the classification scheme. Beyond this, each site should ideally be measured for both size (discharge or volume) and water quality. Two measurements for discharge and volume are commonly used in the limnologic field: cubic-feet-per-second (CFS) for flowing water and acre-feet (AC/FT) for standing water. The definitions and field methods for calculation of both these measurements are in Appendix D.

It was beyond the scope of this Water Resource Inventory Project to do a detailed water quality measurement for all the sites visited. The classification scheme delineates sites according to biological quality, chemical quality, sedimentation and thermal problems. A zero has been inserted at the appropriate level on the inventory card where this information is lacking. Any water quality information included in this report came from other research projects either completed or in progress in the study area.

During the last month of the study, when data collection was considered complete and all sites had been classified, data was evaluated in accordance with original design goals (Appendix D). A priority in the project was to compile a list of perennial water sources in the study area. Sources were classified as perennial on the basis of vegetation, detailed historic records, known flow rates and authoritive confirmation. This list was then field checked and finalized via helicopter. Another project priority was to investigate and/or verify stream source information. Many perennial and "important" intermittant water sites lacked any information on source(s). The streams and lakes designated as important (according to hiker use or wildlife use) were checked by helicopter or fixed-wing aircraft to ascertain flow source.

A third priority was evaluation of water quality throughout the study area. Available data was analyzed in accordance with Appendix F, Water Quality Testing--Interpretation of Results. If the quality of the water was below the acceptable level it was noted on the field card and in the classification number for the site.

River miles, when used to indicate site locations, are from the "Grand Canyon Guide" (Belknap 1969. Westwater Books, Boulder City, Nevada, 48p.), or the "Colorado River Guidebook" series (Pewe 1968. Lebeau Printing Company, Phoenix, Arizona.). The terms 'right and left', when used in conjunction with river mile locations, refer to an indicated side of the river as one faces downstream. Plant names are from "Arizona Flora" (Kearney and Peebles 1964).

The presence of certain plant species has been used throughout this project as an indication of perennial surface waters. Since little field work has been done in identification of small perennial water sources in the Southwest, literature on this subject is noticeably lacking. Refer to Appendix H for a more complete discussion of vegetation as it relates to perennial water.

The majority of information generated by this inventory is data to be analyzed at some later date by computer. However, the basic data will be locally available to individuals seeking water resources information on specific sites, and not as a large, synthesized overview of regional hydrology. Appendix E presents an outline of a computer classification which could be used to analyze much of the data resulting from this study.

Results:

Table 1 lists all known perennial water sources within the study area, a total of 57 identified perennial sources (21 perennial streams or stretches of streams and 36 perennial springs or seeps which may or may not feed into perennial streams). Of the 36 known perennial springs or seeps, 17 arise from the Muav Limestone; four arise from the Bright Angel shale; three from the Tapeats Sandstone; two each from the Redwall Limestone, Coconino Sandstone, and Supai Formation; one each arises from the Esplanade Sandstone and Toroweap Formation; and the sources of four are unknown.

Other results, comprised of basic information on perennial, intermittent, ephemeral and inactive water sources, consist of site record cards on the 500-plus individual water sources inventoried in this project, as well as area maps indicating exact site locations. The individual site records and maps indicating their locations are on permanent file with the Division of Resource Management, Grand Canyon National Park.

Table 1. Known perennial[1] water sources within Grand Canyon National Park.

| Site No. | Name | Location | Geologic Source |
|---|---|---|---|
| BA-3 | Boucher Creek[2] | NE of Eremita Mesa | ------- |
| BA-79 | Bright Angel Creek | River Mile 87.6 (right) | ------- |
| BA-57 | Angel Spring | | Muav Limestone |
| BA-56 | Emmett Spring | | Muav Limestone |
| BA-59 | Ribbon Spring | | Muav Limestone |
| BA-13 | Roaring Springs | | Muav Limestone |
| BA-58 | Transept Spring | | Muav Limestone |
| N-17 | Buckfarm Creek | River Mile 41 (right) | ------- |
| BA-24 | Burro Spring | Pipe Creek | Bright Angel Shale |
| VT-5 | Cliff Spring | Cape Royal | Toroweap Formation |
| BA-78 | Colorado River | USGS Gaging Station | ------- |
| HP-78 | Copper Creek | River Mile 110.2 (left) | ------- |
| BA-76 | Crystal Creek | River Mile 98.2 (right) | ------- |
| BA-49 | Crystal Spring | | Tapeats Sandstone |
| KP-26 | Deer Creek | River Mile 136.2 (right) | ------- |
| KP-11 | Deer Spring | | Muav Limestone |
| KP-42 | Unnamed Spring | | ? |
| BA-68 | Garden Creek | River Mile 89 (left) | ------- |
| BA-26 | East and West Springs | | Muav Limestone |
| VT-9 | Grandview Spring | Hance Canyon | Muav Limestone |

Table 1. (continued)

| Site No. | Name | Location | Geologic Source |
|---|---|---|---|
| VT-8 | JT Spring | Hance Canyon | Muav Limestone |
| KP-28 | Havasu Creek | River Mile 156.7 (left) | ------- |
| S-2 | Havasu Springs | | Supai Group |
| KP-14 | Unnamed Spring | | Redwall Limestone |
| S-6 | Unnamed Springs | | Supai Group |
| BA-74 | Hermit Creek | River Mile 94.9 (right) | ------- |
| BA-30 | Dripping Springs | | Coconino Sandstone |
| BA-10 | Santamaria Spring | | Esplanade Sandstone |
| BA-6a | Unnamed Spring | | Tapeats Sandstone |
| BA-104 | Unnamed Spring | | Coconino Sandstone |
| HP-83 | Hundred and Twenty Mile Creek | Blacktail Canyon | ------- |
| KP-34 | Hundred and Fifty Mile Creek | River Mile 149.7 (right) | ------- |
| KP-27 | Kanab Creek | River Mile 143.5 (right) | ------- |
| VT-23 | Little Colorado River | River Mile 61.4 (left) | ------- |
| N-8 | Nankoweap Creek | River Mile 52.5 (right) | ------- |
| N-10 | At Last Spring | | Muav Limestone |

Table 1. (continued)

| Site No. | Name | Location | Geologic Source |
|---|---|---|---|
| KP-31 | Olo Creek | River Mile 145.5 (left) | ------- |
| BA-105 | Phantom Creek | West side of Bright Angel Canyon | ------- |
| BA-61 | Haunted Spring | | Muav Limestone |
| BA-60 | Phantom Spring | | Muav Limestone |
| HP-68 | Royal Arch Creek | River Mile 116.4 (left) | ------- |
| HP-67 | Shinumo Creek | River Mile 108.6 (right) | ------- |
| PP-47 | Shinumo Spring | | Muav Limestone |
| PP-35 | Tapeats Creek | River Mile 133.7 (left) | ------- |
| PP-1 | Tapeats Spring | | Muav Limestone |
| PP-11 | Thunder River | Tributary of Tapeats Creek | ------- |
| PP-7 | Thunder Spring | | Muav Limestone |
| N-14 | Vasey's Paradise | River Mile 31.9 (right) | Redwall Limestone |
| HP-22d | Unnamed Seep | Turquoise Canyon | Bright Angel Shale |
| HP-27c | Unnamed Seep | Slate Canyon | Muav Limestone |
| KP-43 | Unnamed Seep | River Mile 148.2 (right) | ? |
| KP-44 | Unnamed Spring | River Mile 155 (right) | ? |
| KP-45 | Unnamed Seep | River Mile 138 (right) | Tapeats Sandstone |

Table 1. (continued)

| Site No. | Name | Location | Geologic Source |
|---|---|---|---|
| KP-47 | Unnamed Seep | River Mile 152.7 (right) | Muav Limestone |
| KP-51 | Unnamed Seep | 140-Mile Canyon | Bright Angel Shale |
| N-18 | Unnamed Seep | River Mile 35.5 (left) | ? |
| S-46e | Unnamed Seep | Forster Canyon | Bright Angel Shale |

[1] Perennial is as defined in Appendix D. Sources are classified as perennial on the basis of detailed historic records indicating the source has not gone dry within historic times, the presence of maidenhair fern (*Adiantum capillus-veneris*), or other confirmation that the source has not gone dry within historic times. Further research will no doubt identify other perennial sources within the study area. Sources which may possibly be perennial, and have never been known to go dry, but lacking sufficient field or historic records include: Bedrock Canyon Creek (PP-40), Clear Creek (BA-82), Galloway Canyon Creek (PP-41), Grapevine Canyon Creek (BA-80), Matkatamiba Canyon Creek (KP-35), Monument Canyon Creek (BA-46), Noble Spring (PP-25), Pipe Spring (BA-25), Slate Creek (BA-75), South Big Spring (PP-28), Stone Creek (PP-42), and White Creek (PP-36).

[2] A stream classified as perennial may be perennial for part or all of its length. Sources of streams, when springs which feed them are not listed, are unclear or unknown.

Discussion:

As indicated in Table 1, two locations within the study area are noticeably lacking in perennial water sources, as defined. The Kaibab Plateau with numerous intermittent water sources, and the Coconino Plateau with relatively few intermittent water sources, are both largely underlain with highly permiable Kaibab Limestone. Twenter (1962) noted that no large springs issue from the Kaibab Limestone, indicating that ground water probably drains from the formation into the underlying rocks. This, in addition to the fact that Kaibab Limestone occupies such a large outcrop area on the relatively level Kaibab and Coconino Plateaus, should account for the lack of perennial water in those locations.

Of the 36 identified perennial springs or seeps within the study area, the 17 which arise from the Muav Limestone indicate its importance as a local aquifer. The majority of springs and seeps (intermittent and perennial) inventoried by Huntoon (1977) in the Western Grand Canyon District, 35 of 87 total springs and seeps, were positioned stratigraphically in some member of the Muav Limestone. The Muav is highly fractured and channelized, is largely underlain by the impervious Bright Angel Shale, and has been referred to many times as a good aquifer. When underlain by the Bright Angel Shale, the Muav Limestone is capable of yielding large quantities of water to the surface (Metzger 1961, Twenter 1962). The Muav Limestone promises to be the source of many smaller perennial seeps and springs in the study area which have not been identified in this phase of the inventory.

The Bright Angel Shale is the source of the second largest number of perennial seeps and springs within the study area, for a total of four perennial sources, although these sources are small. Other formations as noted in Table 1 contribute, to varying degrees of volume and number, other perennial water sources, and Appendix B should be consulted regarding further information on the relationship between geologic structure and availability of water in the Grand Canyon region.

Intermittent and ephemeral water sources predominate in the region. Of the 500-plus inventoried water sources, only 57 (approximately 11 percent) are known perennials, while the remainder (approximately 89 percent) are intermittent or ephemeral. While intermittent sources receive water from springs or long-term runoff (melting snow) and ephemeral sources only contain water in direct sources to runoff (see Appendix D for more complete definitions), there is some degree of difficulty in separating the two if historical background information is lacking. The appearance of intermittent sources may be deceptive as well, as some go dry for only several seasons a decade. An example would be Clear Creek (BA-82), a possibly perennial stream, but which was recorded as being dry at its confluence with the Colorado River in June 1965 (Johnson and Sanderson 1968). While it is difficult to quantitatively relate precipitation and runoff to the occurrence of local surface water resources, some inferences

may be made. Little precipitation fell during the years of 1976 and 1977 and many water sources were dry for the first time on record, as indicated by historic information gathered on water site data cards. However, the winter of 1978-79 was very wet, causing many intermittent streams to flow throughout the summer of 1979, when they no doubt had previously been dry by June. As several of these sites had not been inventoried prior to the spring and summer of 1979, their volume and apparent summer-constant flow were deceptive when viewed from the perspective of one year's data.

## Summary and Conclusions:

Data was gathered on 500-plus surface water sources in the Grand Canyon region. The availability of water was found to be closely related to geologic structure, seasonality, annual precipitation, and other factors. Fifty-seven perennial water sources have been identified of the basis of historic records and vegetative analysis, comprised of 21 perennial streams and 36 perennial seeps or springs, which may or may not feed into the perennial streams. The Muav Limestone is the major geologic formation in which perennial seeps and springs arise, although other formations may be of local importance.

Intermittent water sources predominate in the region, with the major perennial streams (with the exception of the Colorado River) being related to large spring systems on both the north and south sides of the Colorado River. The Coconino and Kaibab Plateaus are noticeably lacking in perennial water sources. A variety of other water sources have been identified, including natural lakes, playa lakes (absent from the primary study area and rare in the region), potholes, wells, improved springs, and catchment tanks.

Additional research will no doubt reveal more perennial water sources within the study area. Further investigations into the relationship between plant species and perennial sources will provide a more complete verification of perennial sources. The Muav Limestone appears as a possible source of many smaller seeps and springs which were not identified in this phase of the project.

## APPENDIX A:

### History of Hydrogeographic Research, Grand Canyon National Park

A history of the hydrogeographic research in Grand Canyon National Park will logically follow closely the history of geologic research in this same region. As geologic formations dictate the principal sources of water in Grand Canyon, this history notes many geologic research developments, as they often mention water availability, permeability, and spring locations.

In the year 1540, the viceroy of New Spain, interested in the accounts derived from a Franciscan monk of the latter's travels in the territory now called New Mexico, sent an exploring expedition into that region under the command of Vasquez de Coronado. One of Coronado's captains, named Cardinas, with a party of twelve men, reached the pueblos of the Moquis and repaired them. With Indian guides he was led to a portion of the Colorado, far distant from that seen by others. The history states that after 20 days' march, over a desert, they arrived at a river, the banks of which were so high that they seemed to be 3 or 4 leagues in the air. The most active of the party attempted to descend, but came back in the evening, saying that they had met difficulties which prevented them from reaching the bottom; that they had accomplished one-third of the descent, and from that point the river looked very large.

Several times during the succeeding two centuries, the lower part of the river was visited by Catholic Priests. In 1744, a Jesuit missionary passed through the region and in 1776 another Catholic missionary pursued a southwesterly course from the Great Salt Lake and reached the Colorado at a point that appears to have been almost identical with that attained, from the opposite direction, by Cardinas more than two centuries before.

The story of Cardinas, that had formed for so long a time the only record concerning this rather mythical locality, was magnified rather than detracted from by the accounts of one or two trappers, who professed to have seen the canyon. The establishment of military posts in New Mexico and Utah made it desirable to ascertain how far the river was navigable and whether it might not prove an avenue for the economical transportation of supplies to the newly occupied stations.

There was no appropriation that would enable the War Department to accomplish this service until the summer of 1857 when the Secretary of War provided funds for the exploration of the Colorado River and directed Lt. Joseph C. Ives to organize an expedition. The main object of the work being to ascertain the navigability of the Colorado, detailed information upon that point was also forwarded as the expedition proceeded. The results of the exploration, so far as the navigable portion of the Colorado, are found in a map in the hydrogeographic report. The Department of Natural History was under the charge of Dr. Newberry; his report upon the geology of the region traversed is regarded by Ives as the most interesting and valuable result of the explorations. The accompanying maps were by Egloffstein, who went with Ives as topographer. The privation and exposure to which Egloffstein freely subjected himself, in order to acquire topographical information, has resulted in an accurate delineation of every portion of the region traversed. In 1861, J.C. Ives, published the first full length technical book on the Colorado River entitled "Report Upon the Colorado River of the West" (Ives 1861).

On May 24, 1869, ten men in four boats pushed off from Green River, Utah, into the waters of the Green River. They were a group of former

soldiers, mountain men, and adventurers, led by Major John Wesley Powell. Their aim was to explore the unknown canyons of the Green and Colorado Rivers. The plateau uplands were explored by the Powell Survey in 1870, and the canyons of the Colorado River again in 1871-72. His report on the Colorado River, including the famous diary, was finally published in 1875 as "Exploration of the Colorado River of the West" (Powell 1875), and contained extensive notes on regional geology and the availability of water. Although purporting to concern only the 1869 trip, the diary actually included observations and place names from the second expedition.

During the progress of Powell's geologic investigations new questions in structural and in dynamic geology were presented demanding more extended examination and thus when the various U.S. Geogrophic and Geological Surveys were consolidated the work was incomplete. At this time, with his hearty support, Clarence King was made Director of the Survey, and Powell himself, of the Bureau of Ethnology. Thus Powell was by circumstances taken from the field of geologic research so long cultivated by him and placed in a field in which he had intermittently been engaged for many years. The change was supposed to be permanent, and he gave up all thought of continuing his work as a geologist. The abandonment of his subject of study could be transferred to Captain Dutton, who had been his assistant and collaborator for several years, and who already completed a monograph upon an adjoining and intimately related district--that of the high plateaus of Utah.

In his report "The Tertiary History of the Grand Canyon" (Dutton 1882), Dutton does not undertake to give an exhaustive account of the entire range of the geology of the district, but limits himself to the discussion of its Tertiary history and of the problems of physical geology. The "Tertiary History", the first published of the USGS monographs, made extensive use not only of maps (the first, basic maps of the area) and the geologic sections and diagrams of the scientist, but also of woodcuts, photographs and line drawings aimed at more appreciative eyes and done by two of Grand Canyon's most famous artists, Thomas Moran and William H. Holmes. The "Tertiary History" has kept its vitality as a research monograph and as an artistic interpretation precisely because it does not specialize. The text accompanying the atlas refers to water resources and their occurrence in the area specifically. Dutton delineates springs and water pockets throughout the area and gives explanations as to their relation to the geology of the area. Many side canyons were personally explored by Dutton, Moran and Hughes. He discusses the interrupted quality of flow in the canyon springs that is so obvious today and calls the prospects of water supply upon the Kaibab Plateau "discouraging."

Between 1883 and 1895, Dr. Charles D. Walcott described in greater detail the Grand Canyon group of Powell in a series of publications in the American Journal of Science (Walcott 1880, Walcott 1883, Walcott 1894). During the next 10 to 12 years, not much progress was made concerning knowledge of the character and stratigraphy of the older

rocks in the Grand Canyon. Detailed geologic work demands an accurate topographic base map, and no good map of the Grand Canyon existed until the publication, between 1906 and 1908, of the Vishnu Temple, Bright Angel and Shinumo topographic sheets, on the scale of 1:48,000. The topography of these maps, by F.E. Mathes and R.T. Evans, met the requirements of the geologists. Dr. Noble added much to knowledge concerning the general geology and erosional history of the Shinumo quandrangle and the map which accompaines his bulletin, "The Shinumo Quandrangle, Grand Canyon District, Arizona, 1914 (Noble 1914)," represents the first geologic mapping done in the canyon that attains the standard of accuracy and detail set for the Geologic Atlas of the United States.

In 1925, E. C. LaRue published the results of his study of the Colorado River, "Water Power and Flood Control of Colorado River below Green River, Utah," (LaRue 1925). The purpose of this report was to present the facts regarding available water supply and all known dam sites on Colorado River between Cataract Canyon, Utah and Parker, Arizona and to show the relative value of these dam sites. The Geological Survey had collected records of discharge of some of the tributaries of Colorado River for many years, but it was only since 1920 that the establishment and maintenance of satisfactory gaging stations on the Colorado River itself had been possible. Such stations, at the date of LaRue's publication, were operating at Lees Ferry above the Paria River, in the Grand Canyon at Bright Angel Creek and at Topock below the railway bridge. LaRue had previously prepared the first comprehensive report on the utilization of Colorado River, published in 1916 by the Geological Survey as Water-Supply Paper 395. The 1925 report contains accounts of tributary flow and available water sources.

In 1917, Herbert E. Gregory, with the USGS, published "The Geology of the Navajo Country" (Gregory 1916). The region bordering the Colorado River canyons between Little Colorado and San Juan Rivers and extending southward to the line of the Atchison, Topeka & Santa Fe Railway, at the time, was inaccessible. Satisfactory maps were lacking, roads were few, trails were poorly marked, and water is still scanty and generally poor. Geologic field work in such a country is necessarily reconnaissance; some of it, in fact, is exploratory. The primary objective of his investigations, begun in 1909 and continued during 1910, 1911, and 1913, was to "spy out the land", with a view to suggesting ways in which the country could be more fully utilized. The region is arid and the geologic field work was therefore designed chiefly to obtain information concerning the water supply. Streams and springs as well as canyons and washes were examined, and the sedimentary formations were studies somewhat in detail. Where the demands of the particular problem in hand permitted, geologic mapping was carried on and the most significant geologic features were noted.

In 1934, Douglas Johnson lectured to laymen at the Rice Institute on "Evolution of the Grand Canyon District." This lecture was later published

in the Rice Institute Pamphlet. Johnson, professor of physiography at Columbia University, discussed the water resources in the canyon and their relation to the geology. He drew his information largely from his own 23 years of study and his travels in the Grand Canyon.

In the summer of 1933, the study of the rim rocks of Grand Canyon and their correlatives in the region was started for the purpose of supplementing previous work on the underlying sandstone and of answering some of the many questions related to the general program of educational work in Grand Canyon National Park. Due to the assistance of the Trustees of the Carnegie Institution of Washington and of its president, Dr. John C. Meriam, this program of research was made possible through the placing of generous grants at the disposal of Edwin D. McKee, Park Naturalist, Grand Canyon National Park, and Research Associate of Carnegie Institute of Washington. This was the beginning of an in-depth, specialized study of each layer of the Grand Canyon by Ed McKee. His first publication was "The Coconino Sandstone--Its History and Origin", issued in November 1933. In the study of the Coconino formation, both field and laboratory investigations were carried on. Almost every locality where it is well exposed was visited and at each the thickness was measured and the strata were carefully examined for any features which might aid in the interpretation of their genesis. This paper and the papers to be later published by McKee were unique in that the observations and conclusions concerning the formation being studied apply only to the formation in the region studied--Grand Canyon National Park--whereas other studies to this point in time were either very general in subject or area (not special to the Grand Canyon region.)

McKee went on to publish the following research reports on the Grand Canyon, many of which were to be written after he had left the Park Service and joined with the USGS:

1938 Environment and History of Toroweap and Kaibab Formations
1945 Cambrian History of the Grand Canyon Region
1954 Moenkopi
1969 History of the Redwall Limestone
1969 Stratified Rocks of the Grand Canyon
1975 The Supai Group, Subdivision and Nomenclature

These publications now serve as a ready base for research currently going on in the canyon and for research that has been completed in recent years. Most of the publications are based mainly on field work done in the park, some of which was exploratory in nature and produced information on sites never before visited by researchers.

A groundwater investigation of the South Rim area, Grand Canyon National Park, Arizona, was made at the request of the National Park Service to determine whether a sufficient water supply could be developed to increase adequately the supply for Grand Canyon (Village) and Desert View. D.G.

Metzger, USGS engineer in charge of the project, published his results in 1961, "Geology in Relation to Availability of Water Along the South Rim Grand Canyon National Park, Arizona" (Metzger 1961). The conclusions of his study show that two possibilities of developing additional water for the village are the capture and transport of more water from springs at Indian Gardens and development of the springs in Hermit Creek. If the two sources did not provide the quantity of water needed or if the cost of development was too high, then studies of the water resources of the North Rim area were recommended. There was little or no possibility of developing water in the Desert View area.

This publication is invaluable not only for the conclusions reached concerning availability of water for the South Rim Village, but for its discussion of Grand Canyon geology and water resources. At the same time, the National Park Service began monitoring springs as possible sources of water for Grand Canyon Village.

Since the early 60's, many specialized research projects have been carried out to study the water supply in and around Grand Canyon National Park. Some of the more specific ones, in addition to other notable publications discussing local water resource information, are discussed below:

Hevly, R.H. 1961. Notes on aquatic non-flowering plans of northern Arizona. Plateau 33:88-92.

This mentions some common algae found in the area and where they were collected. There are lists of collections and sites of Characeae, mosses, liverworts and ferns.

Twenter, F.R. 1962. Geology and promising areas for ground water development in the Hualapai Indian Reservation, Arizona. Geol. Surv. Water-Supply Paper 1576-A. U.S. Govt. Print. Off., Wash. D.C. 38 p.

The geology and ground water resources of the Hualapai Indian Reservation were studied to determine the possibility of developing additional water for livestock purposes. The major streams in the area are ephemeral tributaries of the Colorado River. The principal aquifer in the area of this report is the Muav limestone, though small springs issue from the Precambrian rocks and Bright Angel shale and seeps occur at the base of the Tapeats sandstone.

USGS began publishing Water Resource Reports in Arizona from 1891 to the present. A yearly report on ground water is included in these publications as well as specialized area reports.

A cooperative program to provide the hydrogeologic knowledge needed has been in operation between the State of Arizona and the U.S. Geol. Survey

since 1939; since 1942, the State Land Commissioner has been the cooperative representative for the State. The current cooperative ground water program in Arizona consists of three major parts: (1) statewide ground water survey, (2) comprehensive ground water investigations in selected areas and (3) studies related to specific hydrologic problems. The "Annual Report on Ground Water in Arizona" is a summary and analysis of the hydrologic data collected under the statewide ground water survey.

Johnson, P.W. and R.B. Sanderson. Spring flow into the Colorado River; Lees Ferry to Lake Mead, Arizona. 1968. Ariz. State Land Dept. Water Res. Rpt. No. 34. U.S. Geol. Surv., U.S. Dept. of the Interior. 26 p.

The purpose of this report is to describe briefly all the springs visited during the 1960 trip and to compile all known additional discharge data for the springs. The study covered 16 sites. Some of the earliest hydrologic information available for the canyons of the Colorado River was collected by LaRue in 1923 during a boat trip down the Colorado River from Lees Ferry, Arizona, to Needles, California (LaRue 1925). In 1950, S.F. Turner, J.H. Gardiner and J.A. Baumgartner of the U.S. Geological Survey initiated a plan for the investigation of spring flow in some of the canyons of the Colorado River; led by the late John Baumgartner several trips were made from the canyon rims down the cliffs to the source of some of the principal springs. In addition, inflow data were collected during three boat trips from Lees Ferry to Lake Mead--by John Baumgartner in 1953, R.B. Sanderson and P.W. Johnson in 1960 and R.M. Myrick, F.M. Bell, L.B. Leopold and others in 1965. A trip to Havasu Creek, Tapeats Creek and Blue Spring by J.D. Hem and J.L. Hatchett in June 1951 provided data on the chemical quality of the water at these places.

Butchart, H. 1970. Grand Canyon Treks. La Siesta Press, Ca. 72 p.
Butchart, H. 1975. Grand Canyon Treks II. La Siesta Press, Ca. 48 p.

In 1945, Harvey Butchart moved to Flagstaff, Arizona, and took up the project of covering all the inner Grand Canyon trails. He hiked not only the maintained trails but also the abandoned paths throughout Grand Canyon National Park. In 1970, La Siesta Press published "Grand Canyon Treks" by Butchart. This book mentions all water sources Harvey used in the inner canyon and notes on their reliability. In 1975, Harvey had a second book published, "Grand Canyon Treks II", to provide similar information for trails further west and further east of the treks described in his first book.

Carothers, S. W., J. H. Overturf, et al. 1974. History and bibliography of biological research in Grand Canyon with emphasis on the riparian zone. Unpubl. Colo. River Research Rpt., Grand Canyon, Ariz. 137p.

This discusses and critiques the literature surrounding historical biological research performed at Grand Canyon. It contains a checklist of plants, fish, amphibians and reptiles, birds and mammals and mentions where research has been done. There is also a bibliography divided by topic.

Huntoon, P. W. 1970. Hydromechanics of the ground water system in the southern portion of the Kaibab Plateau, Arizona. Ph.D. dissertation, Univ. of Ariz.

This is an analysis of the ground-water system of the Kaibab Plateau, including a description of the geology and permeability of the rock layers.

Huntoon, P. W. 1974. The karstic ground-water basins of the Kaibab Plateau, Arizona. Water Resources Research 10(3): 579-590.

This work discusses the hydrology of the Kaibab Plateau. Bright Angel Creek is discussed in detail as it drains an area of the Plateau second in size only to the Thunder River drainage.

Huntoon, P.W. 1977. Relationship of tectonic structure to aquifer mechanics in the western Grand Canyon District, Arizona. Off. of Water Res. and Tech., U.S. Dept. of the Int. Water Res. Series No. 66. 51 p.

This report will define the geologic occurrence of ground water supplies in the western Grand Canyon district and use those criteria to locate potentially productive drilling sites. Most of the ground water in the western Grand Canyon district occurs in the Rampart Cave Member of the Muav limestone which is the basal carbonate in the Paleozoic section. Although half of the large springs in the district are associated with faults and drain definable parts of the adjacent plateau, the other large springs demonstrate that faulting is not required for their development. Seeps and small springs occur throughout the district and illustrate that flow through the rocks is planimetrically distributed. Water yielded by the small seeps and springs moves primarily along joints and partings along bedding planes.

The Rampart Cave member of the Muav Limestone is the major aquifer in the Western Grand Canyon District based on spring locations in the walls of the Grand Canyon. Permeabilities of the Paleozoic rocks are locally enhanced by faulting. Caves are not associated with springs in the area. Prospects for developing large ground water supplies in the district are dim because: (1) the total recharge is small, (2) permeabilities are small, and (3) there are no extensive permeable zones under the plateaus in which large quantities of water are in storage.

Kubly, D. M. 1975. An annotated bibliography of limnologically related research on the Colorado River and its major tributaries in the region of Marble and Grand Canyons. Natl. Park Service, Grand Canyon Natl. Park. 27 p.

This was an attempt to indicate the status of limnological knowledge of this area and represents a good selection of the literature available on the subject at the time. It also provides a list of sources where each article may be found.

Cooley, M.E. 1976. Spring flow from pre-Pennsylvanian rocks in the southwestern part of the Navajo Indian Reservation, Arizona. Geol. Surv. Prof. Paper 521-F. U.S. Govt. Print. Off., Wash. 15 p.

From 1946 to 1950, the USGS, at the request of the Bureau of Indian Affairs (BIA) made a series of hydrologic investigations to help alleviate water shortages in several places on the reservations. In 1950, the USGS in cooperation with the BIA, began a comprehensive regional investigation of the geology and ground water resources of the reservations. A well developed program supported by the BIA and the Navajo Tribe was carried on concurrently with the regional investigation and is being continued by the Navajo Tribe. The principle objectives of these investigations were: (1) to determine the feasibility of developing ground water supplies for stock, institutional and industrial uses in particular areas and at several hundred well sites scattered throughout the reservation and in adjoining areas owned by the Navajo Tribe; (2) to inventory the wells and springs; and (3) to appraise the potential for future water development.

Cooley, M.E., B.N. Aldridge and R.C. Euler. 1977. Effects of the catastrophic flood of December 1966, North Rim area, Eastern Grand Canyon, Arizona. Geol. Surv. Prof. Paper 980. U.S. Govt. Print. Off., Washington. D.C. 43 p.

The purpose of this investigation was to reconstruct the components of the flood of December 1966 in eastern Grand Canyon as indicated by field evidence and to obtain the information necessary to document an extreme hydrologic event in a semiarid environment. Although there is evidence of previous mudflows in eastern Grand Canyon, no documentation of the phenomenon exists in the literature on hydrology or geomorphology in Arizona. This report describes the distribution and magnitude of precipitation, streamflow and channel modification that resulted from the storm of December 1966 and documents the mudflows that resulted from the flood. The reports related the effects of the flood to those of previously known floods and to the prehistoric and historic occupation of the Grand Canyon. Evaluation of streamflow and flood damage data from the Grand Canyon and the Kaibab Plateau indicates four distinct centers of high runoff; the largest area is along the south edge of the Kaibab Plateau and includes parts of Bright Angel, Clear Lava, Kwagunt and Nankoweap

Creek basins. The other areas of high runoff were (1) Modred, Merlin, and Gawain Abysses in Shinumo Creek basin (2) near the North Rim Entrance Station and (3) near the ridge known as Cocks Comb in North Canyon Wash and South Canyon Basins. A map noting watercourses and spring sites is included.

Foust, R. D., Jr., M. B. Muroy and G. M. Van Fleeteren. 1977. A study of the chemical composition of Monument Creek, Grand Canyon. Research Review, Grand Canyon Natl. Park, Ariz. Unpubl. Ms.

## APPPENDIX B:

### Geology and Water-Bearing Properties of the Formations

The following is a condensed version of D. G. Metzger's study of the Grand Canyon entitled "Geology in Relation to Availability of Water Along the South Rim, Grand Canyon National Park, Arizona." It is a ground water investigation of the South Rim area, at the request of the National Park Service to determine whether a sufficient water supply could be developed to increase adequately the supply for Grand Canyon (Village) and Desert View. For the purpose of the water resource inventory, it provides a clear view of the relationship between geologic structure, lithology and ground water in Grand Canyon National Park.

### INTRODUCTION
by
D.G. Metzger

"In order to evaluate the ground water resources of an area it is essential to have an adequate knowledge of the geologic frame work. In the Grand Canyon area, the occurence of water is related not only to the lithologic character of the sedimentary formation but also to the geologic structure.

Most of the discussion is limited to rocks of Paleozoic age, which offer the best possibilities for development of ground water, because all but one of the springs issue from these rocks. The Precambrian rocks, found only in the inner gorge of the Grand Canyon, are discussed briefly. The Moenkopi formation and the Shinarump member of the Chinle formation of Triassic age are not considered important because they are exposed only as small erosional remnants east of Desert View, and thus are not considered as potential ground water reservoirs."

Pre-Cambrain Rocks

<u>Vishnu Schist</u>--50% of rocks are gneisses
20% intrusives
30% schists

All rocks of the Vishnu schist and accompanying intrusive rocks are dense and offer little possibility as sources of water. However, where the Vishnu schist is overlain by the Tapeats sandstone, deep disintegration along fractures was observed and it probably occurred before the deposition of the sandstone. Ground water that moves downward through the Tapeats sandstone or along faults may proceed farther downward into this zone of disintegration. The amount of water available would be very small, however, as shown by the small yield of a spring in the small canyon east of Indian Gardens.

<u>Grand Canyon Series</u>--Unkar group
Chuar group

The Unkar group is composed of the Hotauta conglomerate, Bass limestone, Hakatai shale, Shinumo quartzite and Dox sandstone. The Chuar group is exposed only in small areas west of the junction of the Colorado and Little Colorado Rivers, in the North Rim area. No springs are known to issue from the Unkar group and because of its depth at which it occurs below the South Rim it is not considered a source of ground water. It is recognized that the buried, isolated hills of the Shinumo quartzite may influence the movement of water within the Cambrian sedimentary rocks.

Paleozoic Rocks

<u>Tonto Group</u>--Tapeats sandstone [Middle Cambrian Age]
Bright Angel shale
Mauv limestone

The Tapeats sandstone is well cemented and forms a sheer cliff. In many places it is a quartzitic sandstone, but locally it is friable near the top. It is conformably overlain by the Bright Angel (B.A.) shale, which retards the downward movement of water. Probably a small amount moves through the shale, especially through fractures. Several springs issue along bedding planes of the Tapeats sandstone. A common feature associated with seeps issuing from the Tapeats sandstone along Hermit and Monument Creeks is salt crystals.

The B.A. shale, middle unit of the Tonto group, is composed in ascending order, of soft green micaceous, sandy shale and thin beds of sandstone; brown limestone; soft green micaceous, sandy shale; and alternating layers of shale and purplish-brown sandstone. The most important hydrologic characteristic of the B.A. shale is the retardation of the downward percolation of groundwater. The low permeability of the B. A. leads to the accumulation of ground water in the overlying formation, the Muav limestone, in areas where structural conditions are favorable.

The Muav limestone, uppermost unit of the Tonto group, consists of thin to thick-bedded bluish-gray limestone and dolomite having a mottled appearance and numerous thin bands or lenses of buff or greenish shaly material. The Muav limestone rests conformably upon the B.A. shale and is unconformably overlain by the Redwall limestone. This unit is the source of ground water for numerous springs in the Grand Canyon area. Solution channels occur in the limestone units of the Muav and ground water moves readily through the formation. Most of the springs along the South Rim issue from the limestone units of the Muav. Where the Muav is an aquifer it is underlain by the B.A. shale, which retards the downward percolation of ground water.

Temple Butte Limestone [Devonian Age]

The Temple Butte (T.B.) limestone of Devonian Age occurs as deposits in channels cut into the Muav limestone. No springs are known to issue form the T.B. limestone and because of its small outcrop area it is considered of little value for the storage or transmission of ground water.

Redwall Limestone [Mississippian Age]

The Redwall limestone is a light-gray and grayish-blue crystalline limestone containing chert, generally stained red by wash from the red siltstone of the overlying Supai formation. It rests unconformably upon the Muav and is unconformably overlain by the Supai formation. One of the most recognizable features of the Redwall limestone is the presence of solution channels that allow the transmission and storage of large quantities of ground water. Along the South Rim the ground water has drained from the Redwall, owing to the downcutting of the canyon and it offers little likelihood of yielding water. Blue Spring to the east and Havasu Spring to the west issue from the Redwall limestone. At these places, regional structure has provided a means for water to collect in the Redwall limestone.

| | |
|---|---|
| Aubrey Group--Supai formation | [Pennsylvanian & Permian Age] |
| Hermit shale | [Permian Age] |
| Coconino sandstone | " " |
| Toroweap formation | " " |
| Kaibab limestone | " " |

The Supai formation is composed for the most part of alternating siltstone and fine-grained sandstone. It is unconformably overlain by the Hermit shale. The Supai formation is only moderately cemented, but because it is composed of siltstone and fine-grained sandstone, water does not move readily through it, although some downward percolation of water does occur. One spring, Santa Maria Spring, issues from the Supai formation.

The Hermit shale is composed of red sandy shale and fine-grained friable sandstone. At the type locality in Hermit Basin the Hermit shale contains large amounts of siltstone and claystone and thus it retards the downward percolation of ground water. Under these conditions, water occurs on top of the shale in the basal few feet of the Coconino sandstone. Where the Hermit shale grades into siltstone and sandstone in the eastern part of the Grand Canyon, it permits the downward percolation of water, although the movement may not be very great.

The Coconino sandstone is very fine to medium grained, is cross-bedded, and consists of well-sorted rounded to sub-angular clear, stained, and frosted quartz grains. It rests conformably upon the Hermit shale and it is conformably overlain by the Toroweap formation. The lithologic character of the Coconino sandstone permits the downward percolation of ground water. Where the Hermit shale below forms an aquiclude, the downward movement of ground water is retarded and the Coconino sandstone is an aquifer. Throughout most of the Kaibab Plateau area, however, the Coconino is above the water table and therefore offers no possibilities for the development of ground water. The sandstone is sufficiently porous to provide large potential storage.

The Toroweap formation consists in the western and central Grand Canyon of two red-bed sequences separated by a massive limestone unit and in the eastern Grand Canyon of a light colored crossbedded and gnarly bedded sandstone. It rests conformably on the Coconino sandstone and is unconformably overlain by the Kaibab limestone. The water-bearing properties of the Toroweap in eastern Grand Canyon are similar to those of the Coconino sandstone.

The Kaibab limestone is composed of thick-to-thin bedded calcareous sandstone and sandy magnesian limestone. Chert is common in some of the limestone. It rests unconformably on the Toroweap and underlies the present erosion surface of large aerial extent in the Grand Canyon area. Although there are few localities in northern Arizona where the Kaibab limestone contains water, it plays an important part in the hydrology of the region because of its permeability and its large outcrop area. The ground water that issues as springs from underlying formations along the South Rim is a good indication of the amount of water that percolates downward through the Kaibab. As the total discharge of springs on the South Rim (except Blue Spring) is small, it is obvious that the recharge per unit area is small. A good soil cover has formed on the Kaibab and much of the precipitation doubtlessly is lost from the soil by evaporation and transpiration. Locally, small springs and seeps issue on top of relatively impermeable beds in the Kaibab limestone.

Triassic Sedimentary Rocks

Moenkopi Formation

The Moenkopi is composed of siltstone and sandstone, mostly red to red-brown and is 300 to 400 feet thick. It is an erosional remnant of small extent and cannot be considered a potential ground water reservoir in this area.

Shinarump member of the Chinle formation.

The Shinarump varies greatly, ranging from fine-grained sandstone to conglorerate in irregular lenses. Its value as a water resource is similar to the Moenkopi.

The importance of structure to the occurrence and movement of ground water cannot be overemphasized. The regional structure doubtlessly governs the regional movement of ground water, but the monoclinal flexures and faults affect the direction of movement locally.

East Kaibab Monocline--Waterloo Hill (W.H.) section<br>
(dip to the N & NE) Grandview (G.V.) section<br>
Desert View (D.V.) section<br>
Cedar Mesa (C.M.) section

The Waterloo section is the northwestward extension of the east monocline near Coconino Point. This monoclinal flexure extends about 7 miles and then bifurcates again forming the D.V. and C.M. sections. The "throw" in the W.H. flexure is about 600 feet near the SE bifurcation and about 1,000 feet at the northern bifurcation. The maximum dips range from 22 1/2 to 30 degrees to the NE.

The D.V. and C.M. sections result from the bifurcation of the W.H. section about 3 miles southeast from Desert View. The D.V. flexure trends toward westward from the bifurcation to near Desert View, then turns N and parallels the canyon rim for 6 miles, to the place where it is cut by the Colorado River. The flexure has a "throw" ranging from 600 feet at its origin at the bifurcation to 900 feet at D.V.

The C.M. flexure trends N from the point of bifurcation for 3 miles, then NW to where it enters the canyon. The "throw" in the flexure increases from about 400 feet at the bifurcation to 600 feet northward near the canyon rim. The flexure passes into a fault on the north side of the Colorado River.

The G.V. section is the westward extension of the east Kaibab monocline from Coconino Point. The G.V. section extends W for about 10 miles and then trends NW to where it intersects the Grand

Canyon rim about 2 miles E of Grandview point. North of Grandview it turns more to the W, passing through Cottonwood and Grapevine Canyons; then it trends more to the N to where it occurs at Cremation Canyon. It passes from a monocline to a normal fault and the fault appears to fade out near the Colorado River because the trace of the fault is not reflected in the Tapeats sandstone on the N side of the Colorado River. The "throw" of the G.V. section is about 600 feet near the point of bifurcation and about 400 feet to the NW where the flexure passes into the canyon.

Bright Angel Fault

The B.A. fault intersects the canyon at the W side of Grand Canyon Village and trends NE. It passes along the slope E of Indian Gardens into a small canyon E of Garden Creek, crosses the Colorado River and extends up Bright Angel Creek on the N side. It has a throw of about 180 feet near Indian Gardens, the strata being dropped to the east. The springs at Indian Gardens are closely associated with the fault, which has been an effective "collection gallery" for ground water in the vicinity and yield about 300 gallons per minute. The largest spring issues from the E slope of the canyon along the fault, at the base of the Muav limestone.

In the Grand Canyon area the regional dip is small (1 - 2 degrees) and water tends to move downdip on top of relatively impermeable layers. Where the regional dip is interrupted by monoclinal flexures, water may follow these flexures.

APPENDIX C:

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APPENDIX C (Con't.)

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33. Basic ground-water data for southern Coconino County, Arizona, by E. H. McGavock. 1968.

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2. Bibliography of U.S. Geological Survey water-resources reports for Arizona, May 1965 through June 1971, compiled under the direction of H. M. Babcock. 1972.

10. Ground-water resources and water use in southern Navajo County, Arizona, by L. J. Manns. 1976.

Issued Annually. Annual Report on ground water in Arizona, Spring 19-- to Spring 19--. (designated earlier as Water-Resources Reports; since 1972 as Arizona Water Commission Bulletins)

## HYDROLOGIC INVESTIGATIONS

Hydrologic investigations include areal resource appraisals, data collection other than that which is part of the Hydrologic-Data Program and research activities. Investigations in progress in Arizona, as of January 1977, are listed below.

A. Water resources of southern Coconino County.
   To appraise the total water resources in an area where both extremely deep aquifers and near-surface perched water bodies occur.

B. Reconnaissance study of the water supply for the Lake Mead N.R.A.
   To determine source and chemical quality of all potential water supplies in the recreational area.

K-T. Appraisal of ground-water conditions in the State by areas.
   To show in map form current ground-water conditions including depth to water, change in water level, and chemical quality of the water.

## RESEARCH AND REGIONAL PROJECTS

Ecohydrology of arid region vegetation. (Project Chief: R. M Turner, Tucson, Arizona.)
   Vegetation changes on the Colorado River between Glen Canyon Dam and Lake Mead as documented by comparing pre-1963 photographs with new photographs of the same scenes. Streamflow records are analyzed to explain the changes.

Summary appriasals of the Nation's ground-water resources.
   Summary of the distribution, availability and quality of ground water and its importance in the water supply of 21 water-resource regions. Arizona is included in two regions: Lower Colorado Region and Upper Colorado Region.

APPENDIX D:

Research Design for FY 1979

Objective

The surface water resources of Grand Canyon National Park are to be inventoried as part of the Ecological Survey of the park. Objectives of the inventory are basically two-fold: to inventory surface water resources with respect to their access by,and public health of humans, i.e. hikers, and secondly, to inventory these water resources in regard to their support of the biota, i.e. primarily wildlife and riparian ecosystems.

Methods

For fiscal year 1979, the water resources inventory will be conducted for the follwing eight USGS quandrangle maps:

| | |
|---|---|
| Bright Angel | Nankoweap |
| DeMotte Park | Powell Plateau |
| Havasupai Point | Supai |
| Kanab Point | Vishnu Temple |

These quandrangles denote the most accessible and most readily used areas in Grand Canyon National Park and have thus been chosen for this primary study. Eventually, the water resources for the entire park and vicinity will be inventoried and mapped.

The inventory project will proceed in five phases:

1. Derive as much information as possible from maps, literature, searches, and personal communication. Identify areas where further information is needed. Prepare preliminary classification system.
2. Supplement phase one information with field data from areas identified as lacking water resource data. Classify field and literature data to the extent possible.
3. Examine classification scheme for responsiveness to needs. Alter as necessary.
4. Derive groupings of data for storage in a computer at some future date.
5. Prepare report for management on surface water resources in the study area as known at the time. The data gathered will be examined for appropriateness for publication.

The classification scheme adopted (Table 1) addresses biological concerns, endangered or threatened species as required by law, political concerns, limnological concerns, and public health and access. The classification

is a hierarchical system (from general to specific) designed to emphasize the public health aspects of surface water for the park visitor, especially the hiker. To derive the classification and the code, the numbers in the scheme are added together to give one number. This number classification has the advantage of permitting the meaningful grouping of the surface waters and a secondary advantage of permitting easy computer storage and mapping of data gathered.

Once areas lacking in water resource information are identified, field data will be gathered on these areas. Access to the areas will be by fixed-wing aircraft, helicopter, motorized vehicles, on foot and by boat. A water resources inventory card (Table 2) will be completed for each site or source, outlining the information needed for later classification and mapping. See Table 3 for a cost-benefit analysis of field work by fixed-wing versus helicopter versus hiking.

Volumes of moving water resources will be expressed in cubic feet per second (CFS) when it is possible to calculate volume of flow. The formula for calculating CFS will be:

$$d \times w \times v = CFS$$

(when $d$ = average stream depth in feet;
$w$ = width of stream in feet;
$v$ = flow velocity in feet per second)

Volumes of standing water sources will be expressed in acre-feet (AC/FT) when it is possible to calculate standing water volume. One acre-foot equals the amount of water required to cover one acre to a depth of one foot and is equivalent to 43,560 cubic feet of water or about 326,000 gallons. Calculating the volume of standing water requires the average diameter and the average depth measurements for the source. According to the tentative classification system (Table 1), a Pond/Lake source is calculated to be 20.87 feet average diameter by 1 foot deep (0.1 AC/FT) or more.

Completion of the inventory will result in the plotting of all water sources on eight USGS topographical maps, the compilation of corresponding inventory cards on each site or source, preparation of all information for computer storage and a narrative report to management, to be completed by October 1979.

# WATER RESOURCE INVENTORY CLASSIFICATION

## CATEGORIES

10,000 with respect to permanence
- 1,000 with respect to continuity in space
  - 100 with respect to origin
    - 10 with respect to volume and nature of source
      - 1 in relation to nearest perennial source
        - .1 with respect to legally threatened and endangered biota
          - .01 with respect to primary value or use
            - .001 with respect to secondary value or use
              - .0001 with respect to water quality (w.q.)
                - .00001 with respect to source of w.q. problem
                  - .000001 with respect to nature of w.q. problem

## DEFINITIONS

<u>Acre-foot (AC/FT)</u> is the quantity of water required to cover 1 acre to a depth of 1 foot and is equivalent to 43,560 cubic feet or about 326,000 gallons, or 1,233 cubic meters.

<u>Cistern</u> is a large receptacle for storing water; especially, a tank, usually underground, in which rain water is collected for use. For this classification, the term cistern includes its intake (cachment) area.

<u>Continuous</u> stream is one that does not have interruptions in space. It does not have wet and dry stretches.

<u>Cubic foot per second (CFS)</u> is the rate of discharge representing a volume of 1 cubic foot passing a given point during 1 second, and is equivalent to approximately 7.48 gallons per second or 448.8 gallons per minute or 0.02832 cubic meters per second.

<u>Developed Spring</u> is a spring that has been dug, piped, pumped, and/or completely contained in order to obtain maximum discharge for human use of some sort. The term "developed" does not include those springs of which a portion has been diverted (with pipes, ditches, or other method); a developed spring is one in which the entire discharge is being utilized.

<u>Endangered</u> species means any species which is in danger of extinction throughout all or a signficant portin of its range (U.S. Fish and Wildlife Service 1978a.). Its peril may result from one or many causes -- the present or threatened destruction, modification or curtailment of its habitat or range; over-utilization; disease or predation; inadequacy of existing regulatory mechanisms; or other natural and man-made factors.

<u>Ephermeral</u> stream is one that flows only in direct response to precipitation. It receives no water from springs and no long-continued supply from melting snow or other surface source. Its stream channel is at all times above the water table. The term may be arbitrarily restricted to streams or stretches of streams that do not flow continuously during periods of as much as one month. *

Intermittent stream flows only at certain times when it receives water from springs or runoff. If it is spring fed, the intermittent character of the stream is generally due to fuctuations of the water table whereby the stream channels stand a part of the time below and a part of the time above the water tables. If fed by runoff, the surface source is generally the gradual or long-continued melting of snow in a mountainous or other cold tributary area. The term may be arbitrarily restricted to streams or stretches of streams that flow continuously during periods of at least one month. *

Interrupted stream is one which contains (a) perennial stretches with intervening intermittent or ephermeral stretches or (b) intermittent stretches with intervening ephermeral stretches.

Perennial stream is one which flows continuously. Perennial streams are generally fed in part by springs, and their upper surfaces generally stand lower than the water table in the localities through which they flow. *

Playa Lake is a shallow, wind-scoured basin that may cover a large area. They are characteristic of deserts. At irregular intervals, they become the seats of broad, shallow sheets of water called playa lakes which quickly gather and almost as quickly evaporates, leaving mud flats to mark their sites.

Pothole is a hole generally deeper than wide, worn into the solid rock at falls and strong rapids by sand, gravel, or stone being spun around by the force of currents.

Stock tank is an artificial reservoir for stock water; it is local in the southwest.

Storage tank is water artificially impounded in service or underground reservoirs for future use.

Threatened species means any species which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range (U.S. Fish and Wildlife Service 1978a).

Well is an artifical excavation that derives some fluid from the interstices of the rocks or soil which it penetrates, except as the term is not applied to ditches or tunnels that lead ground water to the surface by gravity. It is applied, however, to excavations from which water can be drawn by means of siphons. A water well necessarily extends into the zone of saturation.

* Pond/lake, Pothole, and Stock Tank may be classified as perennial, intermittent and ephermeral.

TABLE 1. Proposed Water Resource Inventory Classification Draft *

10000 Perennial Water Source
20000 Intermittent Water Source
30000 Ephemeral Water Source
40000 Inactive Water Source (dry for at least 5 years)
  1000 Continuous Water Supply/Single Source
  2000 Continuous Water Supply/Multiple Source
  3000 Interrupted Water Supply/Single Source
  4000 Interrupted Water Supply/Multiple Source
  5000 Not Applicable (i.e. standing water source)
    100 Natural Water Source
      10 Flowing Water ( $\geq$ 50 CFS)
      20 Flowing Water ( $\geq$ 10, $<$ 50 CFS)
      30 Flowing Water ( $\geq$ 1, $<$ 10 CFS)
      40 Flowing Water ( $\geq$ .1, $<$ 1 CFS)
      50 Flowing Water ( $\geq$ .01, $<$ .1 CFS)
      60 Flowing Water ( $<$ .01, CFS or 4.488 gpm)
      70 Pond/Lake ( $\geq$ .1 AC/FT or 4,356 $ft^3$)
      80 Pothole ( $<$ .1 AC/FT)
      90 Playa Lake
    200 Man-Altered/Artifical Water Source
      10 Developed Spring
      20 Ditch
      30 Well
      40 Storage Tank
      50 Cistern
      60 Stock Tank
        1 $\geq$ 8 mi. to Next Perennial Source
        2 $\geq$ 7, $<$ 8 mi. to Next Perennial
        3 $\geq$ 6, $<$ 7 mi. to Next Perennial
        4 $\geq$ 5, $<$ 6 mi. to Next Perennial
        5 $\geq$ 4, $<$ 5 mi. to Next Perennial
        6 $\geq$ 3, $<$ 4 mi. to Next Perennial
        7 $\geq$ 2, $<$ 3 mi. to Next Perennial
        8 $\geq$ 1, $<$ 2 mi. to Next Perennial
        9 $<$ 1 mi. to Next Perennial Source
          .1 Endangered Plant Species
          .2 Threatened Plant Species
          .3 Endangered Animal Species
          .4 Threatened Animal Species
          .5 Does not Support Endangered or Threatened Species
          .6 Insufficient Information Available on the Site
            .01 Ceremonial/Religious
            .02 Domestic Use, developed or undeveloped
            .03 Recreational Use, Swimming, Bathing & Drinking
            .04 Agriculture and Livestock Use
            .05 Fishing
            .06 Asthetics
            .07 Outstanding Scientific Value
            .08 Supports Riparian Vegetation
            .09 Sediment Transport

.001 Ceremonial/Religious
.002 Domestic Use, developed or undeveloped
.003 Recreational Use, Swimming & Bathing
.004 Agriculture and Livestock Use
.005 Fishing
.006 Asthetics
.007 Outstanding Scientific Value
.008 Supports Riparian Vegetation
.009 Only One Main Use
.0001 Water Quality Problem (Public-health)
.0002 Water Quality Problem (Non-Public Health)
.0003 No Water Quality Problem
.0004 Insufficient Information Available on the Site
.00001 Problem Source Outside Park
.00002 Problem Source Within Park
.00003 Problem Source Within & Outside Park
.00004 Problem Source Undefined
.000001 Biological Problem
.000002 Chemical Problem
.000003 Biological & Chemical Problem
.000004 Sedimentation Problem
.000005 Thermal Problem
.000006 Other Problem

* This is a temporary classification system, field tested, but subject to further changes and updates.

## GRAND CANYON N.P. WATER RESOURCE INVENTORY

SITE NO.:____________

SITE LOCATION:____________________________________________ DATE:____________

TIME:____________

ASPECT OF FLOW: SW S SE E NE N NW W NAME:____________

PHOTO: YES NO ELEVATION:____________ DATA SOURCE:____________

| | | | site vegetation | PROM | HT | COVER |
|---|---|---|---|---|---|---|
| STREAM<br>SPRING<br>SEEP<br>WELL | Avg. depth | inches | | | | |
| | Width | inches | | | | |
| | Flow rate | ft/sec | | | | |
| | Water temp. °F | °C | | | | |
| | Relation to space: Cont. Inter. | | | | | |
| | Deepest pool | inches | | | | |
| POTHOLE<br>LAKE<br>TANK<br>CIENEGAS | Avg. depth | inches | | | | |
| | Avg. diameter | inches | | | | |
| | Water temp. °F | °C | | | | |
| | # of potholes present | | | | | |
| SOIL: | Formation (site) | | NOTES: (presence of salt, wildlife, sanitation problems, weather) | | | |
| | Formation (source) | | | | | |
| | Drainage substrate:<br>%sand %gravel %rock | | | | | |
| UMG/10: | E x N | | | | | |
| Site #: | Card #: | CFS: | | | | |
| CLASSIFICATION: | | | | | | |

DEFINITIONS:

Continuous: uninterrupted flow in space

Interrupted: alternating dry and wet stretches

Vegetation Prominence:
1- species not readily seen, possibly only one present
2- species readily observable, not uniformly distributed
3- species distributed uniformly, possibly co-dominant
4- species dominates in its habitat
5- monoculture; single species dominates habitat

| Height: (m) | Cover: (%) |
|---|---|
| 1- 0 to 0.1 | 1- 0 to 1 |
| 2- 0.1 to 0.5 | 2- 1 to 5 |
| 3- 0.5 to 2 | 3- 5 to 15 |
| 4- 2 to 5 | 4- 15 to 35 |
| 5- 5 to 10 | 5- 35 to 50 |
| 6- 10 to 20 | 6- 50 to 75 |
| 7- 20 to 35 | 7- 75 to 95 |
| 8- 35 and up | 8- 95 and up |

METHODS:

To calculate stream flow rate, place a wood chip in the center of stream flow and time the footage traveled in seconds. This must be done at the SITE LOCATION described on front of card and must be the same site at which depth and width are measured.

TABLE 3

Cost-Benefit Analysis of April 1979 Bass to Hermit Water Resources Hike vs. Fixed-Wing Time vs. Helicopter Time

HIKING:

| | | |
|---|---|---|
| GS-5 Tech. x 8 days x $45/day = | | $350 |
| GS-3 Tech. x 8 days x $35/day = | | $260 |
| per diem, 2 technicians x 8 days x $7/day = | | $112 |
| | Total = | $722.00 |

FIXED-WING TIME:

| | | |
|---|---|---|
| 3 hours at $60/hour | = | $180 |
| GS-5 x 4 hours | = | 22. |
| GS-3 x 4 hours | = | 17. |
| Total | = | $219.00 |

HELICOPTER TIME:

| | | |
|---|---|---|
| 2 hours at $240/hour (allowing for a stop at each major drainage) | = | $480 |
| GS-5 x 3 hours | = | $ 18. |
| GS-3 x 3 hours | = | 13. |
| Total | = | $511.00 |

| HIKING | FIXED-WING | HELICOPTER |
|---|---|---|
| high cost | low cost | moderate cost |
| detailed vegetation descr. | rough veg. descr. | fair veg. descr. |
| much incidental info. | little incidental info. | little inci. info. |
| exact flow rate calc. | poor flow rate calc. | exact flow rate calc. |
| thorough source invest. | fair source investig. | good source invest. |
| much time involved | little time involved | little time involv. |
| low visitor impact | moderate visitor impact | mod. visitor impact |
| collect few specimens | collect no specimens | collect many specimens |
| photographs possible | photographs impossible | photographs possible |

TABLE 4

ESTIMATED BUDGET FY 1979

| | | |
|---|---|---|
| Initial Allotment | + | $6,500.00 |
| Salaries | - | 4,240.89 |
| Miscellaneous | - | 472.65 |
| Field Work: | | |
| Helicopter Time | - | 700.00 |
| Hazard Pay | - | 18.00 |
| River (per diem) | - | 57.00 |
| North Rim Trip | - | 0.00 |
| Bass to Hermit Hike (per diem) | - | 112.00 |
| Equipment: | | |
| Flow Meter | - | 132.00 |
| BALANCE | $ | 759.46 |

APPENDIX E:

Computer Classification

This computer classification is designed to provide the user with access to all data compiled on each site. The data in the list below can be punched on an 80-column computer card for recall by a data storage and retrieval program. The classification number can be used to call only those sites with specific data results, i.e. all perennial sites, all artificial/man-altered sites, etc. A print-out format will be incorporated into the program so that the data on the card can be printed on a page in legible form instead of code.

| Data | Example | No. of Computer Columns Needed |
|---|---|---|
| Site No. | KP103 | 5 space |
| Date | 12-25-79 | 8 space |
| Time | 15:30 | 5 space |
| Aspect | SW | 2 space |
| Photo? | Y or N | 1 space |
| Notes? | Y or N | 1 space |
| Veg. Notes? | Y or N | 1 space |
| Elev. (feet) | 9050 | 4 space |
| Geol. Formation | PCgne (See attached explanation) | 5 space |
| UMG/10 | 20420-400290 | 12 space |
| CFS or AC/FT | 10020 | 5 space |
| Classification | 12345.123456 | 12 |
| | | 61 |
| | | 11 spaces |
| | | 72 computer columns used |

Explanation of Geologic Formation Abbreviations (cited from the USGS Geologic Map of the Grand Canyon National Park, Arizona, 1976. Grand Can. Nat. Hist. Assoc. and Mus. of No. Ariz.)

| | |
|---|---|
| **CENOZOIC** | |
| Slumps, landslides and rockfalls | s |
| Terrace gravels; loose sand and conglomerate | tg |
| River deposits; recent sand, boulders and mud | r |
| Travertine deposits | t |
| **MESOZOIC Triassic** | |
| Chinle Formation Shinarump Member | TRs |
| Moenkopi Formation | TRm |
| **PALEOZOIC Permian** | |
| Kaibab Limestone | Pk |
| Toroweap Formation | Pt |
| Coconino Sandstone | Pc |
| Hermit Shale | Ph |
| Esplanade Sandstone (Supai Group) | Pe |
| **Pennsylvanian** | |
| Wescogame, Manakacha and Watahomigi Formations (Supai Group) | Ps |
| **Mississippian** | |
| Redwall Limestone | Mr |
| **Devonian** | |
| Temple Butte Limestone | Dtb |
| **Cambrian** | |
| Muav Limestone | Cm |
| Bright Angel Shale | Cba |
| Tapeats Sandstone | Ct |
| **YOUNGER PRECAMBRIAN** | |
| Sixtymile Formation (Chuar Group) | PCsm |
| Kwagunt Formation (Chuar Group) | PCk |
| Galeros Formation (Chuar Group) | PCg |
| Nankoweap Formation | PCn |
| Cardenas Lavas (Unkar Group) | PCc |
| Predominantly Diabase Instrusives (Unkar Group) | PCi |
| Dox Formation (Unkar Group) | PCd |
| Shinumo Formation (Unkar Group) | PCs |
| Hakatai Formation (Unkar Group) | PCh |
| Bass Formation (Unkar Group) | PCb |
| **OLDER PRECAMBRIAN** | |
| Granite to granodiorite (Zoraster Plutonic Complex) | $PCgr_1$ |
| Granodiorite to quartz diorite and rarely diorite (Zoro. Plut. Complex) | $PCgr_2$ |

| | |
|---|---|
| OLDER PRECAMBRIAN (cont.) | |
| Elves Chasm Gneiss | PCgne |
| Trinity Gneiss | PCgnt |
| Predominantly mics schist and quartzo-feldspathic schist (Vishnu Group) | PCvs |
| Predominantly amphibolite (Vishnu Group) | PCva |
| Predominantly calc-silicate rock (Vishnu Group) | PCvc |
| Precambrian undifferentiated | pC |

APPENDIX F:

Water Quality Testing[1]

Interpretation of Results

Ratio of Fecal Coliform/Fecal Strep

| | | |
|---|---|---|
| 4.0 | | Strong evidence of human wastes |
| 0.7 | | Strong evidence of non-human wastes |
| 2.0, | 4.0 | Human wastes predominate |
| 0.7, | 1.0 | Non-human wastes predominate |
| 1.0, | 2.0 | Gray area, results uncertain |

[1]As used for the 208 Water Quality Survey, Grand Canyon National Park, Resource Management Division, 1979/80.

APPENDIX G:

Mean Precipitation and Temperature[1]
Grand Canyon National Park

| MONTHS: | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEPT | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MEAN MAXIMUM TEMPERATURES (F°) | | | | | | | | | | | | |
| Inner Canyon | 56 | 62 | 71 | 82 | 92 | 101 | 106 | 103 | 97 | 84 | 68 | 57 |
| Tuweep | 49 | 50 | 61 | 68 | 79 | 89 | 95 | 92 | 85 | 74 | 61 | 49 |
| Desert View | 40 | 43 | 49 | 57 | 69 | 79 | 84 | 81 | 73 | 61 | 49 | 39 |
| South Rim | 41 | 45 | 51 | 60 | 70 | 81 | 84 | 82 | 76 | 65 | 52 | 43 |
| North Rim | 37 | 39 | 44 | 52 | 62 | 73 | 77 | 75 | 69 | 58 | 45 | 40 |
| MEAN MONTHLY TEMPERATURES (F°) | | | | | | | | | | | | |
| Inner Canyon | 46 | 52 | 59 | 69 | 77 | 86 | 92 | 89 | 83 | 72 | 57 | 47 |
| Tuweep | 38 | 40 | 47 | 54 | 64 | 73 | 80 | 78 | 71 | 60 | 48 | 39 |
| Desert View | 30 | 33 | 38 | 44 | 56 | 65 | 71 | 69 | 61 | 50 | 39 | 30 |
| South Rim | 30 | 33 | 38 | 46 | 54 | 64 | 69 | 67 | 61 | 50 | 39 | 31 |
| North Rim | 26 | 28 | 34 | 40 | 48 | 56 | 62 | 60 | 54 | 45 | 35 | 30 |
| MEAN MINIMUM TEMPERATURES (F°) | | | | | | | | | | | | |
| Inner Canyon | 36 | 42 | 48 | 56 | 63 | 72 | 78 | 75 | 69 | 58 | 46 | 37 |
| Tuweep | 26 | 30 | 34 | 40 | 49 | 58 | 65 | 63 | 56 | 46 | 35 | 29 |
| Desert View | 21 | 23 | 27 | 31 | 42 | 51 | 59 | 56 | 59 | 39 | 30 | 21 |
| South Rim | 18 | 21 | 25 | 32 | 39 | 47 | 54 | 53 | 47 | 36 | 27 | 20 |
| North Rim | 15 | 18 | 24 | 28 | 34 | 40 | 46 | 45 | 39 | 31 | 24 | 20 |
| MEAN PRECIPITATION (Inches) | | | | | | | | | | | | |
| Inner Canyon | .72 | .73 | .79 | .48 | .31 | .28 | .79 | 1.31 | .88 | .69 | .51 | 1.31 |
| Tuweep | 1.10 | .90 | 1.25 | .73 | .40 | .40 | 1.28 | 1.97 | .79 | .80 | .77 | 1.31 |
| Desert View | 1.00 | .94 | 1.52 | .75 | .50 | .32 | 1.29 | 1.34 | .99 | 1.39 | .80 | 1.72 |
| South Rim | 1.32 | 1.53 | 1.37 | .92 | .65 | .46 | 1.87 | 2.28 | 1.50 | 1.21 | .95 | 1.61 |
| North Rim | 3.28 | 3.17 | 3.12 | 1.67 | .97 | .76 | 1.86 | 2.53 | 1.81 | 1.50 | 1.44 | 2.62 |

[1]Taken from the Proposed Colorado River Management Plan, 1977.
Grand Canyon National Park

APPENDIX H:

Vegetation as an Indication of a Perennial Water Source

The presence of maidenhair fern (Adiantum capillus-veneris) was used in this study as an indicator of a perennial water source in areas within the Inner Canyon, but not on either the North or South Rims. Only a perennial water source can sustain maidenhair fern and even then, only in shady, protected alcoves or ledges (Arthur M. Phillips-personal communication). Other water-loving species exist in the Grand Canyon region whose presence requires moist mud or rich, moist soil, but whose relationship to perennial surface waters, as defined, was not understood completely enough or early enough in the project to be useful. Columbine (Aquilegia chrysantha), crimson monkeyflower (Mimulus cardinalis), and helleborine orchid (Epipactis gigantea) all require moist mud, surface water, or running water within two to three inches of the surface. These three water-loving species, in addition to maindenhair fern, all have shallow root systems which would appear to be an adaptation to wetter conditions when longer roots would be unnecessary for the gathering of scarce water supplies (Arthur M. Phillips--personal communication). No published research was found to justify the use of any of the four above-mentioned plants as indicators of perennial surface water for this study. However, Kearney and Peebles (1942) and other sources do mention that moist habitats needed to support these species. It is important to note that all perennial sources listed in the results do not necessarily support any of the above species, as comprehensive historical records were used in some instances to identify perennial sources. Likewise, absence of any of the four species does not necessarily imply the source is intermittent or ephemeral. Further literature research or personal communications with botanists could reveal more completely the relationship between plant species and perennial water sources. Prominent phreatophyte species in the Southwest, including cottonwood (Populus fremontii), willow (Salix spp.), mesquite (Prosopis juliflora), and salt cedar (Tamarix chinensis) have not been found to indicate perennial surface water.